Vital steps toward success of endangered plant reintroductions

| Thomas N Kaye

ABSTRACT

Reintroduction of endangered plants faces many challenges, but the survival of some species may depend on its success. What measures should practitioners take to ensure a successful project, and how should success be measured? Steps in the reintroduction process include planning and identification of objectives, finding source material, propagation, site selection, site preparation, outplanting, monitoring, evaluation and interpretation, feedback to improve protocols, communication with others, habitat maintenance, and repeated actions if necessary to meet objectives. Conducting reintroductions as designed experiments and applying the results through adaptive management will maximize the effectiveness of reintroductions.

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Reintroduction of endangered species is a step that becomes necessary when too few populations exist in the wild to sustain long-term viability, or when management objectives call for additional populations in areas where a species has been extirpated. In addition, reintroduction may be implemented to mitigate for population losses caused by habitat development or changes in management priorities, but mitigation of this sort is much more controversial and fraught with ethical concerns (for example, see Allen 1994). In a review of 181 recovery plans for endangered species, one study (Hoekstra and others 2002) found that 72% of plans call for some form of reintroduction. But how does one go about reintroducing a species that is missing from a portion of its historic range?

Population reintroduction is a field still searching for a consistent vocabulary (Armstrong and Seddon 2008). *Translocation* is a term widely used for the same process, and the term can include the wholesale transplanting of individuals or populations from one wild site to another. *Augmentation* is one form of reintroduction that involves adding individuals to an existing population to increase its size and viability. *Introduction* is also sometimes used as a synonym for reintroduction or translocation, but the term also describes the process of nonnative and invasive species movement into a new region. I use the term *reintroduction* here inclusively, meaning all forms of placing plant materials into occupied or unoccupied sites of an endangered species within its historic range or ecoregion, with the assumption that a species may have occurred in any piece of appropriate habitat at some point in the past even if there are no supporting historic records.

Reintroduction is widely understood as a special form of habitat restoration that applies to rescuing or recovering endangered species (Maunder 1992; Falk and others 1996; Armstrong and Seddon 2008). The process of reintroduction faces many unique challenges due to the high value placed on the individual species targeted for improvement. Overcoming gaps in our understanding of species biology and factors that limit plant establishment is crucial (Guerrant and Kaye 2007), because reintroduction in general has been subject to such frequent failure that many regard it as unreliable (Fahselt 2007). Many others have proposed components to the reintroduction process including the International Union for the Conservation of Nature (IUCN 1995). Griffith and others (1989) evaluated the methodology and made recommendations for animals, and Vallee and others (2004) updated guidelines for threatened plant translocations in Australia. Falk and others (1996) provided a comprehensive overview of reintroduction in their edited volume entitled *Restoring Diversity: Strategies for Reintroduction of Endangered Plants*. A well-laid-out procedure to guide reintroductions can maximize the likelihood of success. This article presents a concise step-by-step strategy for guiding plant species reintroductions that emphasizes developing and testing hypotheses about factors that may affect success, allows for feedback through adaptive management as better techniques are developed, and discusses how success can be measured in this process. A few examples from my own experience with rare plants are included.

VITAL STEPS FOR SUCCESSFUL REINTRODUCTION

Plan and Set Clear Objectives

The first step (Table 1) in an effective reintroduction program is to develop a plan of action with clear objectives. The plan does not need to be long and burdened with extensive background information, but it should address each of the steps laid out below. It should consider what state and federal permits may be required, and it should link the current project to any recovery plan or other conservation plans for the species in question. An excellent example of a regional reintroduction plan has been developed for golden paintbrush (*Castilleja levisecta* Greenm. [Scrophulariaceae]) (Caplow 2004), an endangered species endemic to prairies in western Washington and Oregon that has been lost from the southern portion of its range.

Clear goals and objectives, in the form of specific desired outcomes, should be stated succinctly from the very beginning. These will depend on the species and the scope of the project, as well as type of need the project is intended to address. Pavlik (1996) presents an effective scheme for identifying objectives and suggests they can be divided into categories focused on the project success as well as on biological accomplishments. Examples of project-based objectives might include:

- Develop efficient germination protocols for the target species that maximize the number of seedlings per seed.
- Keep costs of propagation below US$ 10 per individual.
- Determine if fall or spring outplanting is superior for plant establishment.
- Educate the public about the significance of the species and its habitat.

Biological objectives can be further divided into quantitative states (for example, number of individuals) and qualitative processes (for example, self-sustaining population size). Typical objectives could include statements such as:

- Establish 500 individuals at each of 2 sites.
- Augment an existing population so that the total population size exceeds 2500 individuals.
- Establish connectivity between 2 isolated populations by establishing a stepping-stone colony of at least 250 individuals within pollinator flight–distance of each.

Objectives for process-based achievements could include:

- Pollination by insects,
- Natural recruitment of seedlings from transplanted individuals, and
- Positive population growth rate.

These differing forms of objectives are not mutually exclusive but can be listed as multiple desired outcomes of the project. They should be crafted so they can be revisited later in the project to evaluate project progress.

Obtain Source Material for Reintroduction

For some endangered species, natural seed production is prolific and seeds are relatively easy to collect. For others, however, seed production in the wild is very low (Figure 1) and (or) variable from year to year. Common limits to natural seed production include seed predation (especially by insect larvae), low pollination service by pollinating insects, inbreeding depression due to isolation and small population size, competition with invasive weeds, and insufficient resources such as rainfall.

TABLE 1

Vital steps in a plant reintroduction program.

Plan and set clear objectives
Short and long-term, state and process objectives
Obtain necessary permits

Obtain source material for reintroduction
Collect seeds, cuttings, and so forth
Maximize genetic diversity
Consult seedbanks for materials

Propagate plant materials
Identify or develop cultivation protocols
Initiate seed increase program

Select appropriate site(s)
Logistical criteria: ownership and management
Biological criteria: within historic distribution, appropriate habitat, manageable invasive species
Use the species as a phytometer to select likely sites

Prepare the site
Conduct prior to planting to avoid later conflicts
Remove threats such as invasive species

Conduct outplanting
Use more than one strategy: hedge bets and compare methods
Frame testable hypotheses
Implement outplanting as a designed experiment

Assess and interpret results
Monitor establishment and collect data
Test hypotheses with statistical methods

Update protocols as indicated by new information
Adaptive management

Communicate results to others
Improve other reintroductions
Build foundation for broader generalizations to advance the field
Report results to Natural Heritage Program or other data-tracking center

Maintain habitat
Some species may require frequent disturbance

Repeat as necessary
Multiple founding events may be necessary to establish a new population

These factors can make it difficult to obtain adequate seeds for propagation in some or most years. But obtaining plant material such as seeds, cuttings, or divisions is crucial for any reintroduction program. Therefore, projects need to identify the type of plant material to be used, determine where the materials will be gathered, and conduct field collection activities. Field collection should maximize the genetic diversity of plant materials so that the reintroduced group of individuals has diversity levels similar to wild populations. In some cases, *ex situ* collections (such as seedbanks maintained by partners with the Center for Plant Conservation) may be available (Havens and others 2006), reducing pressure on wild populations.

Propagate Plant Materials

Plant reintroduction projects have 2 primary techniques available, establishing plants as seeds or as grown plants. Both methods can be used simultaneously but if planting of potted starts is selected, they must be cultivated and made ready for outplanting. In most cases, this will require development of cultivation practices including germination protocols and greenhouse propagation methods (for example, Kaye and Kuykendall 2001). In addition, if plant material availability is limited, the project may need to emphasize propagating plants from seeds or cuttings. Even if sowing seeds is selected as the only method of establishing plants at a site, a seed increase program that considers genetic issues (see Ward and others 2008) may be necessary to generate the amount of seeds necessary for adequate plant establishment, and may require the same level of care as any captive rearing program.

Figure 1. The entire seed output from a single population of Kincaid's lupine may be very low in some years; each set of seeds shown here represents the cumulative fecundity of one site. Low seed output from wild populations can limit the availability of seeds as propagation materials. Photo by Thomas N Kaye

Select Appropriate Site(s)

Some aspects of site selection hinge on project objectives. Projects that intend to establish multiple populations with biological connectivity among them, along with opportunity for dispersal to, and colonization of, new sites, will require much more spatial planning than those that focus on creating a new population at a single location. Regardless of scale, though, all projects will require site selection based on a few common criteria, which are here divided into logistical and biological groups. Logistical criteria include site ownership and management. Sites that are publicly owned or in conservation easement should, in most cases, be given priority over privately owned locations without long-term security. Reintroduction sites should also emphasize those that are managed for conservation purposes with a commitment to endangered species protection.

Biological criteria should prioritize sites within the species' historic range or current ecoregion, with local habitat and soil traits similar to known sites, and with few (or controllable) invasive weeds. Some level of noninvasive, exotic plants may be acceptable in the target habitat. In addition, the site should be of sufficient area to support a population of the size identified in the project's objectives.

In some cases, such as where a species is extirpated from a portion of its historic range, a clear understanding of what makes suitable habitat may be lacking because too much time has passed since the species was observed in the wild (Lawrence and Kaye 2006). One approach to site selection in this situation is to use the species intended for reintroduction as a *phytometer* (the plant's performance becomes the measure of site suitability). Planting several individuals at a large number of sites and measuring plant survival and growth can help identify which sites should be targeted for large-scale reintroduction. This process may also identify site characteristics helpful in selecting additional locations.

Prepare the Site

Site preparation may be the most important step in a successful reintroduction program. Without it, all planning and planting could be wasted effort. Identifying and removing threats to the species survival will be key. If substantial nonnative and invasive weed species are present on the site, reducing them to an acceptable level prior to reintroduction will be necessary to avoid having the endangered species in the way of future treatments, such as herbicide application. Dense, competing vegetation, whether native or nonnative, could limit plant establishment, which means large-scale or local treatments to reduce vegetative cover may be needed. Creating the appropriate vegetation structure (for instance, adequate sunlight or shade), soil fertility, soil microbial conditions, seedbeds, and even topography (for example, excavation to create vernal pools) should be considered at the site preparation stage, prior to reintroduction at the site.

Conduct Designed Outplanting

Using more than one planting strategy in a reintroduction project serves as a bet-hedging tactic to increase the likelihood of initial success. It also provides an opportunity to evaluate techniques and improve methods for subsequent projects or additional work at the same site. Framing testable hypotheses and implementing reintroductions as designed experiments is a crucial component of effective outplantings (Guerrant and Kaye 2007). Testing hypotheses requires selection of treatments and controls, as well as adequate randomization and replication for statistical comparisons.

For example, a study conducted in the West Eugene Wetlands of Oregon used a randomized design to compare various factors that could affect performance of reintroduced endangered plants (Kaye and Brandt 2005). In one species examined, Willamette daisy (*Erigeron decumbens* Nutt. [Asteraceae]) (Figure 2), survival of 186 transplants after 4 y was substantially and significantly (as examined with logistic regression) affected by season of planting (spring or fall) and whether plants were given fertilizer at the time of planting. Individuals planted in spring without added nutrients had 48% survival, while only 3% of fall transplants supplied with fertilizer lived. This comparison of different planting techniques helped to spread the risk that any single approach (or combination of approaches) would fail and has informed additional reintroduction projects for this species at other locations.

Assess and Interpret Results (Compare with Objectives)

Monitoring plant establishment and growth makes it possible to compare on-the-ground results with the project's objectives. In another example from near Eugene, Oregon, careful plot sampling showed that Kincaid's lupine (Figure 3) (*Lupinus sulphureus* Douglas ex Hook. ssp. *kincaidii* (C.P. Sm.) L. Phillips [Fabaceae]) can establish successfully through direct seeding as well as by transplanting greenhouse-grown individuals (Kaye and Cramer 2003). One interpretation of this result was that transplants may be appropriate (although costly) if few seeds are available, while direct seeding may be least expensive if seeds are plentiful. Without follow-up measurements of plant performance, evaluation of project effectiveness may not be feasible. If the reintroduction has been conducted as a designed experiment, plant sampling will be necessary to provide the data needed for statistical comparisons. In other words, if specific hypotheses were identified during outplanting, monitoring (possibly for more than one year) will be necessary to provide the data to test these hypotheses. Following through with this process will ensure that new information is gained from the project and identify additional efforts (such as a second round of planting) needed to meet the original objectives.

Update Protocols as Indicated by New Information (Adaptive Management)

Adaptive management is the process by which on-the-ground experience informs and improves future management actions. Conducting reintroductions as designed experiments and evaluating the results with statistical tools maximizes the quality of the project's conclusions and helps managers fold new information into the restoration process. As improvements to reintroduction techniques are found, they should be incorporated into existing protocols for a given species. If results raise new questions, those questions can be framed as new hypotheses to be tested in the next generation of reintroduction attempts.

Figure 2. Willamette daisy is a good example of how experimentally comparing different methods of reintroduction can dramatically improve project success. An experimental approach showed that planting in spring without fertilizer yielded much higher survival than did fall planting with added nutrients. Photo by Thomas N Kaye

Communicate Results to Others

Sharing information with other practitioners can provide vital information to support reintroductions throughout the range of a given species and build the critical mass of case studies needed to synthesize and make generalizations. Reintroduction conclusions can seem so species- or site-specific that finding commonalities may appear daunting. It may only be after a foundation of basic research has been laid that we will be able to make meaningful contributions to ecological theory.

Providing information on species that were reintroduced, the locations in which they were placed, and the geo-

Figure 3. Monitoring plant establishment and growth is a crucial component of reintroduction programs. Kincaid's lupine was shown to do well when established from seeds and from greenhouse-grown plants. Costs were also tracked and results showed that direct seeding was much less expensive but was appropriate only if many seeds were available. Photo by Thomas N Kaye

graphical source(s) of plant materials to data-tracking centers, such as state Natural Heritage Programs, is crucial for long-term understanding of wild as compared with created populations. In addition, overall planning and tracking of endangered species recovery will rely on up-to-date and accurate information on the size, location, and history of all populations.

Maintain Habitat

Reintroduction does not end after an organism has been placed at a field site. Management of the habitat aimed at supporting the species may need to be continued, in some cases indefinitely. Species of early successional habitats may require frequent disturbances to keep competing vegetation from encroaching and limiting their survival, and continued colonization of habitat by invasive species may need to be addressed over the long term. Therefore, post-planting habitat maintenance may be necessary to give new populations long-term viability.

Repeat as Necessary

Reintroduced populations have uncertain futures. The timing of rainfall after a planting event, for example, may determine whether plants become established. Herbivory by an unusually large population of rodents, large mammals, or insects may eliminate the plants before a population can get started. Vandals may destroy the plants. Failure to establish a population after only one attempt should not always be considered project failure. Instead, projects should anticipate this possibility and plan for it. Founding populations may require multiple reintroduction attempts to achieve establishment. Species whose populations depend on active recruitment from a persistent seedbank, such as pink sand verbena (*Abronia umbellata* Lam. ssp. *breviflora* (Standl.) Munz [Nyctaginaceae]), an endangered annual to short-lived perennial of the Pacific Coast (Kaye 2004) (Figure 4), are good examples of those that may require repeated seeding before a self-perpetuating population may be developed. A conservation strategy for this species on public land calls for multiple seedings to develop a viable population with a resident persistent seedbank at several sites (BLM, USFS, and OPRD 2006).

AN ADAPTIVE MANAGEMENT FRAMEWORK

Although the steps presented here appear as a linear sequence of tasks and accomplishments, reintroduction projects tend to be most effective if the process allows for iterative feedbacks and updates. Adaptive management can occur at all stages, even causing goals and objectives to shift as new information is gathered. If reintroduction actions are performed as experiments that compare different techniques, poorly performing methods can be discarded while more effective methods can be deployed more widely and refined through time. As reintroductions occur their results can be evaluated through monitoring and hypothesis testing (Figure 5). If additional reintroductions are needed to meet project objectives, these, too, can be performed

Figure 4. Pink sand verbena is a rare plant of Oregon's coastal beaches and appears to require repeated seeding events to establish a persistent seedbank. A Conservation Strategy for the species recommends seeding multiple times at restoration sites. Photo by Thomas N Kaye

as comparative experiments. In the example with Willamette daisy described above, the initial tests found that planting in the spring without fertilizer was superior, and further reintroduction attempts used this method but also went on to test for effects of vole herbivory by caging a random set of plants and leaving others unprotected (Thorpe and Kaye 2006). Follow-up habitat maintenance may include more than one technique, such as mowing, controlled burning, herbicide application, and fencing, and their effects can be compared through monitoring and straightforward statistical tests.

CONCLUSION: MEASURING SUCCESS

Reintroduction projects that follow a step-by-step plan with clear objectives can measure their success one objective or task at a time. Because these projects are inherently uncertain and

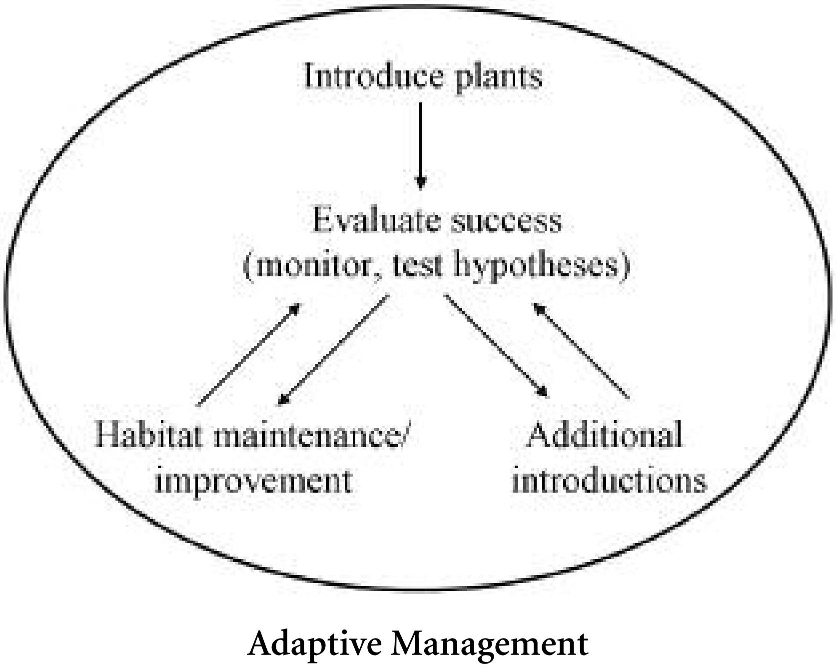

Figure 5. An adaptive management framework for endangered species reintroductions. When plantings are conducted as designed experiments, evaluation of their success can be used to test hypotheses about what methods work best or which habitat factors limit establishment. Follow-up habitat maintenance and additional plantings can test further hypotheses and allow for continued improvements to reintroduction protocols, as well as better generalizations across species and habitats.

often require development of novel methods as they progress, success may best be measured in more than one way. As Pavlik (1996) recommends, separating project contributions (Objectives met? New techniques developed? Public educated?) from biological accomplishments (Number of plants established? Number of populations created?) broadens the manner in which success is evaluated. Measuring success sequentially as projects move forward can keep managers and practitioners focused on the positive attainments of a project and avoid abandoning a reintroduction effort prematurely because of a single failure of outplanted stock.

Ultimately, however, success may be defined in biological terms such as populations that display demographic and genetic function (for example, seedling recruitment, avoidance of inbreeding depression), long-term viability, and even metapopulation processes and unassisted colonization of new sites. Menges (2008) suggests that reintroduced populations may be considered successful if they behave like wild ones and appear to have long-term stability as measured with population viability analysis. He recommends that evaluations of success take a long-term view, because longer windows of observation may be required to adequately measure effects of experimental treatments and population viability.

There will also be situations in which meaningful success is not attained even after substantial effort. It is important for practitioners to decide during the planning process at what point to suspend reintroduction attempts and concede failure. The list of species in need of reintroductions for their long-term conservation is growing, and the limited resources available for this work demands that priority be given to the species in greatest need as well as to those with the highest likelihood of success. Species for which reintroduction consistently fails may need to be passed over in order to assist those with brighter prospects.

The steps outlined here are largely based on common sense, and many of them have been discussed by others in more detail. If there is a unique message in this article, it is the concise combination of these primary recommendations for reintroductions:

- follow a plan with clear objectives,
- incorporate designed experiments,
- include a process for adaptive management, and
- measure success sequentially on a sliding scale that includes both project and biological achievements—and know when to admit defeat and move on to the next challenge.

Finally, reintroduction is a process that may be necessary in some cases to meet conservation goals for a species in jeopardy. The decision to pursue reintroduction represents a significant commitment to conservation planning, funding, and biological needs. In some cases, ethical considerations may be necessary to ensure that the process is conducted for sound reasons (Falk and others 1996) and not, for example, just to mitigate for habitat loss caused by development and financial gain. Climate change in the coming decades may cause suitable habitat for many species to shift across the landscape and challenge us to assist with their migration if they are to survive (McLachlan and others 2007), a process similar to reintroduction but with additional ethical and procedural considerations.

Conservation is generally best served through protection of existing populations and habitat where they already occur (Fahselt 2007), with reintroduction as one tool to increase population sizes, numbers of populations, and connectivity among them.

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